

Natural Gas Infrastructure Reliability

Pathways for Enhanced Integrity, Reliability and Deliverability

September 2000

U.S. Department of Energy

Office of Fossil Energy

and the

National Energy Technology Laboratory



Strategic Center for Natural Gas

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NATURAL GAS INFRASTRUCTURE RELIABILITY

Table of Contents

Executive Summary	1
I. Introduction	3
II. Key Trends and Drivers.....	4
III. Vision and Goals	5
IV. Technology Challenges.....	5
V. R&D Pathways	7
VI. The Collaborative Path Forward.....	11
Appendix A: Senior Executive Visioning Workshop	A-1
Appendix B: R&D Roadmapping Workshop.....	B-1

Executive Summary

In 1998 22.0 trillion cubic feet (tcf) of natural gas was consumed in the United States. By 2020, forecasted consumption ranges from 29.5 tcf in a low economic growth case to 34.8 tcf in a high-growth case.¹ This forecast of a 50% increase in gas consumption is coupled to an era of unprecedented change in the natural gas industry. Deregulation, the rapid pace of mergers and acquisitions, the forecast that the 30 tcf market will be satisfied with only modest price increases, and the associated pressure for financial performance have highlighted concerns over the nation's ability to maintain a reliable natural gas infrastructure – the system for the transmission, storage, and distribution of natural gas.

To address this issue, the U.S. Department of Energy Office of Fossil Energy and the National Energy Technology Laboratory, through the Strategic Center for Natural Gas, sponsored two industry workshops to examine the issues associated with infrastructure and the opportunities for technology development to help resolve them. These workshops respond, in part, to the results of several recent studies that identified infrastructure reliability as a possible hurdle to natural gas growth and supply security.

The first workshop brought together 14 senior executives from the natural gas industry to discuss market, business, regulatory, and technical issues related to infrastructure reliability and define strategic goals for addressing them. The second workshop convened 40 technical experts from industry to outline a research agenda and related public - and private-sector opportunities to collaborate on this agenda.

INDUSTRY OUTLOOK

The findings of the workshops cover a range of market, business, regulatory, and technology concerns.

- The infrastructure is aging at a time when the demand on the system is increasing, requiring attention to life-extension options.
- Storage capabilities and capacity will play an increasing role in assuring gas deliverability.
- Significant construction of new infrastructure will be required to deliver 30 tcf of gas.
- The reduction of damage by “third-parties” (i.e., those other than the owner or operator or pipelines) is critical to maintaining safety and reliability.
- Requirements for 24-hour use cycles, distributed generation, and value-added services will increase as the industry evolves from the simple delivery of a commodity to a set of value-added services and products.
- Consistent government policy and faster, more predictable regulatory decisions are needed to enable timely and cost-effective infrastructure development.
- The DOE technology portfolio should reflect needs for public-benefits R&D and the importance of natural gas as a clean-energy option.
- Technology must play a key role in supporting the existing infrastructure as well as changes to the infrastructure necessary to meet growing demand.

¹ *Annual Energy Outlook 1999*, Energy Information Administration.

The findings of this effort are not exhaustive. They do, however, provide a consensus framework for the identification and planning of collaborative actions needed to assure infrastructure reliability. The results are also consistent with existing studies, and complement existing industry-driven collaborations and activities.

TECHNOLOGY CHALLENGES

The role of technology in assuring infrastructure integrity and reliability is significant. While it is not *the* answer, it can play a major role in many critical areas. There are significant areas where technology development can have a major role in providing public-sector benefits.

Improve Monitoring and Assessment of System Integrity. The national gas infrastructure is both vast and varied. Age, location, and materials of construction are major variables. The ability to remotely and inexpensively monitor and assess systems integrity and status could provide improved means for service-life prediction and defect detection to ensure operational reliability.

Enhance System Flexibility and Throughput. Within the pipeline systems, capacity and deliverability are limited by absolute pressure limits on the pipeline and the rate at which pipeline pressure can be varied. Opportunities for enhancement include improved compressor technology, advanced low-cost storage options, and increasing the allowable line pressure.

Reduce Incidence and Cost of Subsurface Damage. In the vast pipeline infrastructure, damage to underground facilities is the predominant integrity and reliability concern. As well over half of subsurface damage results from third-party infringement, ability to detect these facilities – and provide real-time warning of proximity – would be a vitally important capability.

Improve Capability for Cost-Effective Construction. In the highly competitive, expanding gas industry, the opportunity for new construction materials, technologies, and techniques is great. To deliver on the promise of new technology, however, development must not simply provide new or enhanced capability; it must be provided at low cost or it will not be widely adopted in practice.

Improve Data Quality for System Planning and Regulatory Acceptance. Equally challenging to pure technology development is system planning data and information that can facilitate improved regulatory and permitting processes. Challenges include information to support technology validation and acceptance, improved information on existing system integrity, and supporting information on planned system enhancements, including new and retrofit construction.

THE COLLABORATIVE PATH FORWARD

There is a tremendous amount of knowledge, capability, and resources currently devoted to gas infrastructures. Today's infrastructure is in fact highly reliable. Reliability and deliverability has been maintained as deregulation progresses. For the infrastructure of tomorrow, there are opportunities for collaboration that will yield significant public-sector benefits. The challenge for the path forward is to find collaborations that both build upon current success and define new opportunity for maintaining and enhancing the integrity, reliability, and deliverability of the Nation's natural gas infrastructure.

I. Introduction

The natural gas industry is in the midst of unprecedented change, encompassing market, business structure, and regulatory developments. In addition, increasing demand for natural gas is stressing the capacity of existing infrastructure and will require substantial investments in the construction of new transmission and distribution facilities. A 1999 workshop of industry executives, sponsored by the U.S. Department of Energy, examined the changes in energy markets for natural gas, and identified key challenges facing the expanded use of natural gas. A key finding was that the integrity of the gas infrastructure will be critical in meeting future demands.² Similar findings are presented in the recent National Petroleum Council report on natural gas market growth.³

The U.S. Department of Energy Office of Fossil Energy and the National Energy Technology Laboratory, through the Strategic Center for Natural Gas, sponsored two industry workshops to examine infrastructure issues and the opportunities for technology development to resolve them. These industry workshops responded both to the recent studies and to the growing importance of natural gas as a clean energy source for the nation.

The workshops developed a consensus on the challenges and opportunities for gas infrastructure. While the findings are not exhaustive, they provide a consensus framework for potential collaboration. The detailed results of these two workshops are presented as Appendix A and Appendix B of this report.

The workshops addressed a series of questions:

- What are the key trends and drivers that will shape the natural gas infrastructure of the future?
- What is the vision for this infrastructure?
- What are appropriate goals to achieve the vision?
- What are the major R&D challenges to attaining this vision?
- What are the R&D pathways to solutions?
- What are the collaborative roles the public- and private-sectors can play in assuring infrastructure reliability?

Participants were senior executives and technical experts representing pipeline companies, local distribution companies, integrated energy providers, industry-sponsored R&D groups, industry associations, and several government organizations.

² *Matching Natural Gas Supply and Utilization for the 21st Century: Understanding the Forces of Change in Emerging Gas Markets*, U.S. DOE, January 1999.

³ *Natural Gas: Meeting the Challenge of the Nation's Growing Natural Gas Demand*, the National Petroleum Council, December 1999.

II. Key Trends and Drivers

The trends and drivers that are seen as having the greatest impact on infrastructure are wide-ranging. They encompass market growth and changes in the customer base, regulatory and public policy considerations, technology development, and environmental and safety considerations.

MARKET GROWTH AND CUSTOMERS

There is general consensus that the overall market will grow significantly, and that it will be quite different in structure. Significant changes will occur particularly at the local distribution component of the system, with the types of customers, the specific services, and delivery patterns changing. The role of power generation will dramatically increase in a 30 tcf future. Gas use will double for electricity generation at traditional central-site facilities, with peaking needs and distributed generation increasing dramatically.

REGULATION AND PUBLIC POLICY

In the area of regulation and public policy, the changes resulting from deregulation and industry restructuring have fundamentally altered decades-old patterns. The fragmented nature and pace of deregulation on a regional, state, and local basis creates uncertainty and delays in planning for infrastructure needs. Policy changes have not kept up with a rapidly changing industry. A stable, longer-term policy framework that strongly supports the value of natural gas as a clean power option would enable companies to improve strategic planning for infrastructure needs.

TECHNOLOGY DEVELOPMENT

Overall, technology development patterns have lagged behind the market changes. As the transition from ratepayer-supported R&D funding under FERC to direct industry-supported funding takes place the focus on longer-term, public-benefits R&D is eroding. While new industry collaborations are being developed, the effectiveness of these and other mechanisms for R&D support remains to be seen. There is an over-arching question of market-based vs. public-benefits R&D. Particularly in a deregulated world, what represents public-benefits R&D and how it is to be supported are key questions. Many areas of R&D are considered appropriate as public-benefits activity, but vary in the degree of government support. Public-benefits R&D encompasses environmental, safety, energy security, and longer-term, precompetitive research.

ENVIRONMENTAL QUALITY, SAFETY, AND SYSTEM VULNERABILITY

In general, the need to assure environmental quality and preserve system integrity crosscuts all other issues and trends. Regulatory and policy issues in particular impact the industry's ability to effectively plan and implement the necessary measures. Variability in the infrastructure is an increasing concern with respect to assuring system integrity and reliability. Differences in age, construction and material quality, and the ability to monitor and assess the status of systems are major concerns. New demands on infrastructure and the risks posed by third-party damage are major concerns.

III. Vision and Goals

The vision for the nation's infrastructure reflects two primary drivers – the need to provide the desired services while meeting the expectations of customers and the general public, and the need for pricing that reflects the emerging trend to value-added services and products rather than mere delivery of a commodity.

VISION

“The gas infrastructure of the future will provide customer-specific service in a safe, reliable, environmentally benign, and efficient manner – at prices that are commensurate with the value provided.”

To achieve this vision, goals include:

- Increase pipeline capacity by 10% without changing infrastructure
- Improve the flexibility of the system to respond to load changes
- Continue safety improvement trends:
 - Decrease rate of safety incidents by 50% by 2010
 - Reduce outside force damage by 10% per year
- Establish a system to assess system integrity and trade-offs for use in planning and state and federal regulatory decisions by 2005
- Establish electronic systems to enable seasonal, daily, and hourly delivery of services by 2005
- Develop portfolio of technologies to reduce costs:
 - Reduce construction costs by >20% by 2005
 - Reduce operations and management costs by 30% by 2005, by 50% by 2010
- Decrease the rate of air emissions by 50% per million cubic feet by 2010

IV. Technology Challenges

The role of technology in attaining the vision is key. Goals of enhancing the use of current infrastructure, improving system flexibility, enhancing the integrity and reliability of current and new pipeline systems, and developing technologies for cost reduction all have significant technology development components. In each of the following areas, public-benefits R&D is a significant aspect of achieving the infrastructure vision.

IMPROVE MONITORING AND ASSESSMENT OF SYSTEM INTEGRITY

The national gas infrastructure is both vast and varied. Age, location, and materials of construction are major variables. The ability to remotely and inexpensively monitor and assess systems integrity and status could provide improved means for service-life prediction and failure detection. The development of improved methods and technologies can significantly enhance the integrity of the current infrastructure and help assure the integrity of new infrastructure. Also important is improved data and information management. The combination of improved data (better types of data and improved data quality) and adoption of emerging information management technology can provide the opportunity for improvements in system integrity as well as for related customer services.

ENHANCE SYSTEM FLEXIBILITY AND THROUGHPUT

Within pipeline and storage systems, capacity and deliverability are limited by absolute pressure limits on system components and the rate at which pressure can be varied. The ability to increase either or both of these could allow increased capacity in both current and new systems. Opportunity for enhancement includes improved compressor technology and piping with higher allowable line pressure. Note that line pressure is not strictly a technology issue but a regulatory one due to permissible line pressures. Improvements in storage options and capabilities could provide flexibility to meet expected load change patterns from distributed generation and 24-hour use patterns. Both advanced storage options and faster storage and withdraw cycles could contribute to system flexibility.

REDUCE INCIDENCE AND COST OF SUBSURFACE DAMAGE

In the vast pipeline infrastructure, damage to underground facilities is the predominant integrity and reliability concern. Over the past 10 years, while the amount of gas delivered has *increased* by 25 percent, the number of safety incidents has *decreased* by 38 percent.⁴ However, growth in the gas industry will require added vigilance to maintain this record. Perhaps most importantly, the growing economy means more building and more excavation. This is particularly true with respect to burgeoning communications growth. As well over half of subsurface damage results from third-party infringement, ability to detect these facilities – and provide real-time warning of proximity – would be a vitally important capability.

IMPROVE CAPABILITY FOR COST-EFFECTIVE CONSTRUCTION

In the highly competitive, expanding gas industry, the opportunity for new construction materials and techniques is great. The use of new technology may have multiple benefits. In particular, increased integrity and deliverability would have substantial public benefits. Opportunities include advanced materials, construction tools, and construction techniques. To deliver on the promise of new technology, however, development must not simply provide new or enhanced capability. It must also provide these capabilities at low cost. Without this critical need, the likelihood is very great that the technology will not be widely adopted in practice.

IMPROVE DATA QUALITY FOR SYSTEM PLANNING AND REGULATORY ACCEPTANCE

While not strictly a technology challenge, regulatory acceptance – quickly and efficiently – will be key to realizing the true potential of technology development. Improved development and acceptance of system (national, regional, state, local) planning data and information could significantly improve regulatory and permitting processes. Challenges include information to support technology validation and acceptance, improved information on the status of existing systems, and information on planned system enhancements, including new and retrofit construction.

⁴ The American Gas Institute, *America's Natural Gas Industry Has Safety Record That is a Model for the World*, January 2000.

V. R&D Pathways

The technology challenges outlined in the previous section can be met by addressing a series of R&D pathways in a technology roadmap. These pathways include not only the development of new tools, techniques, and capabilities, but also the development and application of improved data and information to the planning and management of facilities.

There are several elements that crosscut most of the pathways. For example, improved remote sensing has a major role in meeting many needs. This includes above-ground detection of underground facilities, in-pipe inspection and monitoring, and sensors on boring and excavation equipment to sense proximity to underground facilities. Also, many pathways are greatly dependent upon “smart” systems with improved data gathering, communication, and information management capabilities. Most pathways are synergistic. For example, advances in remote imaging could yield cascading improvements in system integrity, flexibility, and reliability. The technology roadmap for infrastructure reliability is presented in Figure 1 and described in the following paragraphs.

CHALLENGE: IMPROVE MONITORING AND ASSESSMENT OF SYSTEM INTEGRITY

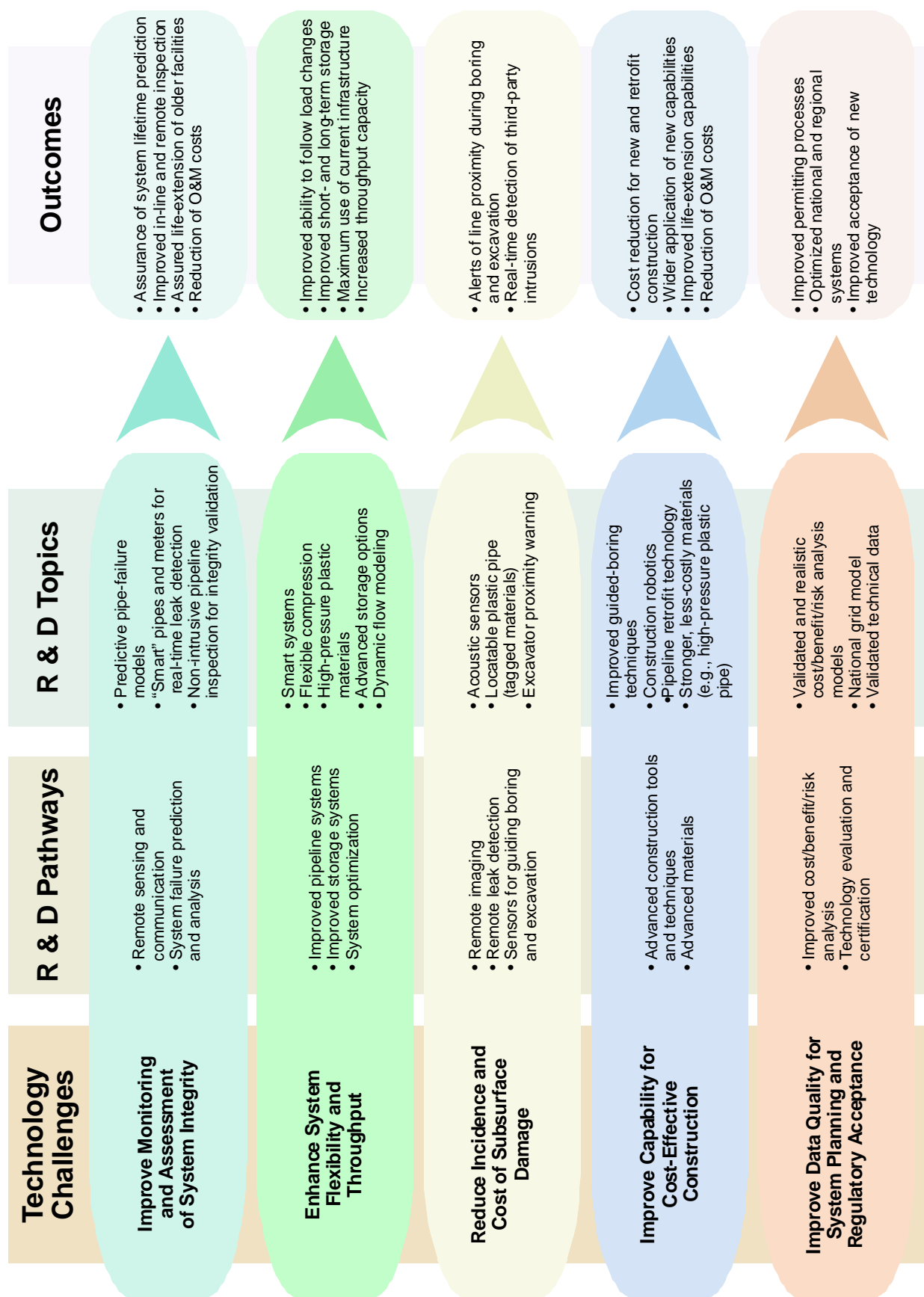
Pathway: Remote Sensing and Communication. Reliable, timely information on both the physical plant (pipes, compressors, actuators, and other hardware) and operational parameters (gas flow, pressure, and volume) is necessary for maintaining system integrity and efficiency. Topics include advanced in-pipe inspection tools, sensors to better identify and characterize damage and leaks, and sensors for dynamic applications with quick response times. A novel preventive approach would utilize a system of sensors and communications to detect when someone was approaching a line and alert a control center to prevent intrusion. A novel approach for data transmission would be to use the pipes themselves as the medium for information transmission, thus removing reliance on radio signals or satellites.

Pathway: System Failure Analysis and Prediction. System control is hindered by a lack of good information on the physical condition of the pipelines and the fact that it is difficult and expensive to find and fix leaks. With improved data streams as input, the development of advanced algorithms and models could support improved analysis of failure modes and prediction of failure potential. Automated information management using these improved data streams and algorithms could result in automated system controls with faster response and significantly reduced operations and maintenance costs, while substantially enhancing the system integrity.

CHALLENGE: ENHANCE SYSTEM FLEXIBILITY AND THROUGHPUT

Pathway: Improved Pipeline Systems. System capacity and the ability to deliver are limited by both the absolute pressure limits on the pipeline and the rate at which pipeline pressure can respond to changes in flowrates using existing compressor technology. It is anticipated that a revision of current (regulatory) operating pressure limitations from 33% to 40% of design capacity would allow significant increases in flow. This is an issue primarily for plastic pipes, but also may be relevant for steel pipes, particularly in older systems. While in many regards a regulatory issue, increased pipe strength capability (and verification thereof) could allow for

Figure 1. Technology Roadmap for Infrastructure Reliability



increased pressure and flow in future systems. There is also room for improvement in the management of transient flow. A better fundamental understanding of dynamic flow, improved transient flow models, and improved real-time data would contribute to optimization while maintaining system integrity. With regard to compressors, worthwhile improvements would include “next-generation” flexible compression and improved modeling of compressor-station components to reduce maintenance and operation costs and improve reliability.

Pathway: Improved Storage Systems. Improved storage options could significantly aid in meeting variable load requirements. Topics include novel on-site storage methods (e.g., storage as methane hydrates), technology to allow increased volumes and higher flow rates without reservoir damage, and strategies and models for optimized long-term storage.

Pathway: System Optimization. Smart systems could optimize deliverability without changes to the physical plant. Combining better data from multi-functional sensors with advanced algorithms could provide rapid-response to system load changes, providing capacity “bandwidth” expansion without changing the hardware in the infrastructure.

CHALLENGE: REDUCE INCIDENCE AND COST OF SUBSURFACE DAMAGE

Pathway: Remote Imaging. Improved above-ground imaging and locating of underground facilities is a critical need. The focus is on the ability to determine subsurface conditions, identify facilities (including non-metallic components as well as potential obstructions), and provide three-dimensional mapping. Inexpensive systems to locate and provide images of underground facilities would be useful, especially if they could also identify the materials of construction without using invasive techniques. Improved capability over conventional methods would allow more precise location and mapping of facilities, particularly for local distribution systems.

Pathway: Remote Leak Detection. Third-party infringement and damage to underground facilities is of great concern to the industry. The development of new sensor technologies to anticipate and discriminate infringements, along with new technologies to contain and repair underground pipe damage, would provide new capability to assure system integrity and reliability. “Smart” pipes could detect infringements and leaks, and then relay data on necessary actions and repairs. A further capability would be pipes that could self-seal as well.

Pathway: Sensors for Guiding Boring and Excavation. One method of preventing infringements would be to develop sensors mounted on excavation equipment. These “on-bucket” or “in-borehole” sensors could detect the proximity of underground facilities and warn operators. Sophisticated versions could be further used to guide excavation in and around underground facilities.

CHALLENGE: IMPROVE CAPABILITY FOR COST-EFFECTIVE CONSTRUCTION

Pathway: Advanced Construction Tools and Techniques. The development of new tools and techniques for new and retrofit construction and repair could provide improved precision at lower cost. Retrofit and rehabilitation technology using new techniques and materials could aid in life extension. Advanced lining technology and techniques could enable low-pressure-to-high-pressure upgrades of existing infrastructure as well as repair of pipe defects. Advanced underground directional drilling technology could provide improved precision at reduced cost.

Combined with the proximity sensors described above, these guided boring technologies could eventually result in the increased use of construction robotics as well as new “keyhole” excavation and trenchless techniques that are more precise and less intrusive than current techniques.

Pathway: Advanced Materials. Development of new materials for pipes that would be tougher, more resistant to corrosion, and able to withstand higher pressures is a major opportunity. Advanced, high-pressure plastic and composite materials and plastic pipe that is locatable (tagged with materials for detection purposes) are of interest. Also important would be the development of internal coatings that could be applied to existing pipes for improved strength as well as to make them smoother to reduce frictional losses. A key component would be a method to apply the coating that was suitably low cost and prevented the coating from getting into compressors and other ancillary equipment.

CHALLENGE: IMPROVE DATA QUALITY FOR SYSTEM PLANNING AND REGULATORY ACCEPTANCE

Pathway: Improved Cost/Benefit/Risk Analysis. Increasing public expectations with regard to environmental health and safety add to the increasing complexities of the regulatory and permitting process. Current regulations often inhibit private investment in new technologies and delay construction. A strategic approach to the permitting process is needed, including consistency in regulatory and safety standards, so that institutional barriers can be overcome in a timely manner. Improved data based on accepted criteria (by regulators and by industry) could result in more realistic cost/benefit/risk analysis models. It is expected that the increased accuracy of such models, particularly with regard to overall risk and technology risk, could contribute to an improved permitting process.

Pathway: Technology Evaluation and Certification. There are many new technologies that are available but not in wide use; most due to higher costs, but some due to concerns over receiving regulatory acceptance. A process – acceptable to regulators, technology developers, and industry users – that would evaluate new infrastructure technology and provide a certification “seal of approval” could aid both cost reduction and the introduction of new technology. The certification could cover technical, environmental, and human factors performance under field conditions. By facilitating the acceptance and field application of new technologies, certification could significantly enhance system integrity and reliability.

VI. The Collaborative Path Forward

The industry is in an era of rapid change and new challenges. It has responded with mergers, acquisitions, new products and services, and new partnerships. Many in industry are already active participants in a variety of collaborative R&D activities. The government must also respond to this changed world. Two specific areas can benefit.

- Analysis and restructuring, as appropriate, of the entire government's research portfolio is needed to reflect the dramatic changes and opportunities for technology development. To facilitate best use of R&D resources and funding, review of the Department of Energy R&D portfolio is appropriate in terms of the relative emphasis on natural gas as a clean energy resource, and on the goals and structure of the natural gas R&D portfolio. This new Department of Energy initiative on natural gas infrastructure reliability represents a step in this direction.
- Opportunities for beneficial changes in regulatory processes can lead to improved use of the current infrastructure, and timely, cost-effective development of new infrastructure. The use of risk-management approaches, for example, has the potential for enhancing safety, reliability, and other public benefits while streamlining the costs and time required to meet the ultimate goals of regulatory requirements.

Change in the overall natural gas industry is fueling commensurate changes in private-sector collaboration and partnerships. Analogous changes in the public-sector can yield both improved public benefits and a better environment for business planning to meet infrastructure needs.

THE GOVERNMENT ROLE

The government can serve an important role as part of an overall collaborative effort to ensure that the best, most cost-effective opportunities for a reliable infrastructure are attained. There are three major areas where the government can serve an effective role.

- Establishing and communicating clear policies with respect to the role of natural gas in the nation's energy policy. Natural gas is emerging as an environmentally preferred energy source. Both regulatory and policy changes can help assure the benefits of natural gas use to the nation.
- Providing leadership in identifying and supporting R&D appropriate to the government role. This includes public benefits R&D and precompetitive R&D to keep the "technology pipeline" full. This is critically important with regulation-supported R&D nearly at an end.
- Serving as an "honest broker" in 1) identifying, validating, and promoting technology solutions to a wide range of stakeholders, including the public and the regulatory community and 2) identifying and supporting opportunities for government/industry collaboration.

COLLABORATION IN TECHNOLOGY DEVELOPMENT

There are significant opportunities for technology development. Table 1 shows the time frames and priority for example R&D topics that have public benefits related to system integrity, reliability, and deliverability. The Department of Energy's role in this technology development can significantly enhance and augment current work in industry and industry-funded collaborations. Furthermore, new collaborations supported or led by the Department can help assure success in new technology pathways.

There is a tremendous amount of knowledge, capability, and resources currently devoted to gas infrastructure. Today's infrastructure is in fact highly reliable. The challenge for the path forward is to find collaborations that build upon current success as well as define new opportunities for maintaining and enhancing the integrity, reliability, and deliverability of the Nation's natural gas infrastructure.

Table 1. Time Frame and Priority for Example R&D Topics

	Near-Term (0-3 Years)	Mid-Term (3-7 Years)	Long-Term (7+ Years)
HIGH PRIORITY	<ul style="list-style-type: none">• Technology to locate and image underground facilities from above ground• Advanced in-line inspection tools• Lower-cost emission systems for compressors• Optical methane and ethane detectors• Locatable plastic pipe and detection of non-metallic pipe• Technology evaluation and certification methodology	<ul style="list-style-type: none">• Three-dimensional imaging of facilities from above ground• Advanced tools and methods for integrity assessment• Sensors and warning systems on excavation equipment• Advanced, high-pressure composite materials• Advanced directional drilling• Enhanced leak detection and communication	<ul style="list-style-type: none">• Intrusion detection and communication• Smart systems with multi-functional sensing (residual life, third-party damage), control-system communication, and rapid-response system control
MEDIUM PRIORITY	<ul style="list-style-type: none">• More realistic economic models for cost/ benefit/risk analysis• Predictive pipe-failure models• Data for improved permit processes	<ul style="list-style-type: none">• Improved storage facilities (design, operations management, pressure and flow measurement)• "Smart" pipes (self-monitoring, self-healing)• Lining technology to allow low- to high-pressure upgrades• Advanced coating and coating-application techniques• Improved system data acquisition	<ul style="list-style-type: none">• Next-generation compressors• Distributed (on-site) storage concepts• Infra-red thermal detection systems
LOW PRIORITY	<ul style="list-style-type: none">• Modeling algorithms for compressor components• Keyhole construction• Improved real-time metering (volume & heat content)	<ul style="list-style-type: none">• Repair and joining of plastic pipes• Internal repair techniques	<ul style="list-style-type: none">• Construction robotics

APPENDIX A:

SENIOR EXECUTIVE VISIONING WORKSHOP

Table of Contents

Executive Summary	A-3
I. Introduction.....	A-4
II. Key Trends and Drivers.....	A-4
III. Vision and Goals	A-7
IV. R&D Challenges.....	A-7
V. Appropriate Government Role.....	A-8
List of Participants.....	A-10

Executive Summary

In 1998 22.0 trillion cubic feet (tcf) of natural gas was consumed in the United States. By 2020, forecasted consumption ranges from 29.5 tcf in a low economic growth case to 34.8 tcf in a high-growth case.¹ This forecast of a 50% increase in gas consumption is coupled to an era of unprecedented change in the natural gas industry. Deregulation, the rapid pace of mergers and acquisitions, the forecast that the 30 tcf market will be satisfied with only modest price increases, and the associated pressure for financial performance have highlighted concerns over the nation's ability to maintain a reliable natural gas infrastructure – the system for the transmission, storage, and distribution of natural gas.

To address this concern, representatives of the natural gas industry met in a workshop sponsored by DOE to outline a vision for the future of the nation's natural gas infrastructure. The workshop responds to the results of several recent studies that identified infrastructure reliability as a possible impediment to natural gas growth and supply security. The workshop brought together 14 senior executives from the natural gas industry to identify key issues related to infrastructure reliability and define strategic goals for addressing them.

The findings of the workshop cover a range of policy, market, and technology concerns.

- The infrastructure is aging at a time when the demand on the system is increasing, requiring attention to life-extension options.
- Consistent government policy is needed to enable timely business decisions for capacity expansion and enhancements to the existing infrastructure.
- Storage capabilities and capacity will play an increasing role in assuring gas deliverability.
- Public perception of infrastructure safety, along with industry concerns over third-party damage, are important considerations for safety and reliability.
- Requirements for 24-hour use cycles, distributed generation, and value-added services will increase as the industry evolves from the simple delivery of a commodity to a set of value-added services and products.
- Faster, more predictable regulatory decisions are needed to enable timely and cost-effective infrastructure development.
- The DOE technology portfolio should reflect needs for public-benefits R&D and the importance of natural gas as a clean-energy option.

The findings of this workshop are not exhaustive. They do, however, provide a consensus framework for the identification and planning of collaborative actions needed to assure infrastructure reliability. The results of this workshop have guided a subsequent workshop to outline specific R&D activities to meet the vision and goals.

¹ *Annual Energy Outlook 1999*, Energy Information Administration.

I. Introduction

The natural gas industry is in the midst of unprecedented change, encompassing market, business structure, and regulatory developments. The reliability of the natural gas infrastructure (here defined as the storage, transmission and distribution components) in meeting the nation's growing demand has been identified as a issue warranting collaborative industry/government effort. A 1999 workshop of industry executives, sponsored by the U.S. Department of Energy, examined the changes in energy markets for natural gas, and identified key challenges facing the expanded use of natural gas. A key finding was that the integrity of the gas infrastructure will be critical in meeting future demands.¹ Similar findings are presented in the recent National Petroleum Council report on natural gas market growth.²

The workshop addressed the following questions:

- What are the key trends and drivers that will shape the natural gas infrastructure of the future?
- What is the vision for this infrastructure?
- What are appropriate goals to achieve the vision?
- What are the major R&D challenges to attaining this vision?
- What is the appropriate government role in assuring infrastructure reliability?

Participants were senior executives representing pipeline companies, local distribution companies, integrated energy providers, industry-sponsored R&D groups, and industry associations. The one-day visioning workshop is followed by a workshop on R&D roadmapping to identify critical R&D needs, the R&D opportunities to meet these needs, and the collaborative roles industry and government can play in meeting these needs.

II. Key Trends and Drivers

The trends and drivers that are seen as having the greatest impact on infrastructure are wide-ranging. They encompass market growth and changes in the customer base, regulatory and public policy considerations, technology development, and environmental and safety considerations.

Market Growth and Customers

There is general consensus that the overall market will grow significantly, and that it will be quite different in structure. Particularly significant changes will occur at the local distribution

¹ *Matching Natural Gas Supply and Utilization for the 21st Century: Understanding the Forces of Change in Emerging Gas Markets*, U.S. DOE, January 1999.

² *Natural Gas: Meeting the Challenge of the Nation's Growing Natural Gas Demand*, the National Petroleum Council, December 1999.

component of the system, with the types of customers, the specific services, and delivery patterns changing.

- The role of power generation will dramatically increase in a 30 tcf future. Gas use will double for electricity generation at traditional central-site facilities, with peaking needs increasing dramatically.
- Increased use of distributed-site power generation will introduce new deliver patterns and demands on distribution infrastructure.
- Innovative industry practices are required that more closely reflect changing patterns of gas use and the value-added nature of the services provided.
- Variable reliability requirements, 24-hour use cycles, and value-added services will change pricing structures.
- Integrated energy companies will continue to grow, along with movement from delivering gas as a simple commodity to more sophisticated energy services, and energy services combined with other services such as communications.

Regulations and Public Policy

In the area of regulation and public policy, the changes resulting from deregulation and industry restructuring have fundamentally altered decades-old patterns. The fragmented nature and pace of deregulation on a regional, state, and local basis creates uncertainty and delays in planning for infrastructure needs.

- Policy changes have not kept up with a rapidly changing industry. A stable, longer-term policy framework would enable companies to improve strategic planning for infrastructure needs.
- There is an opportunity for risk-based planning and management that can provide improved service delivery at greater levels of reliability.
- Flexibility is required in regulatory practices to enable the validation and cost-effective use of new technology in multiple applications.
- The market-driven pace of mergers, acquisitions, and development of a mixture of regulated and unregulated businesses units has eclipsed the regulatory framework. Faster, more predictable regulatory decisions are needed for cost-effective infrastructure development.
- Public expectations of low-cost energy along with “not-in-my-backyard” construction sentiment is at odds with the needs for infrastructure development.
- The siting of new pipelines required for capacity expansion will become more difficult due to regulatory and land-access issues.

Technology Development

Overall, technology development patterns have lagged behind the market changes. As the transition from ratepayer-supported R&D funding under FERC to direct industry-supported funding takes place the focus on longer-term, public-benefits R&D is eroding. While new industry collaborations are being developed, the effectiveness of these and other mechanisms for R&D support remains to be seen.

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- There is an over-arching question of market-based vs. public-benefits R&D. Particularly in a deregulated world, what represents public-benefits R&D and how it is to be supported are key questions. Many areas of R&D are considered appropriate as public-benefits activity, but vary in the degree of government support. Public-benefits R&D encompasses environmental, safety, energy security, and longer-term, precompetitive research.
 - In today's business environment, R&D is increasingly viewed as a cost, not an investment. Given the rapid pace of market and business structural changes, there appears to be little incentive for corporate investments at this time.
 - Price competition and deregulation are decreasing the amount of investment in the "R&D pipeline." As R&D products from the regulated era are still coming to market, the flow of new technology into industry use has continued. A key question is how (and whether) in the future the R&D pipeline will be refilled without direct ratepayer support.
 - Innovation is international in nature. With increasingly complex business relationships, innovation (including both technology and business practices) transcends simple geographical lines.
 - Emerging technology areas include technology for life extension, technology to enhance new transmission and storage capacity, and improved systems planning and information management.

Environmental, Safety, and System Vulnerability

In general, the need to assure environmental quality and preserve system integrity crosscuts all other issues and trends. Regulatory and policy issues in particular impact the industry's ability to effectively plan and implement the necessary measures.

- The costs for safety and environmental regulatory requirements are increasing while the ability to recover these costs is static.
- Clean air act requirements for compression facilities make siting and new capacity additions increasingly difficult, despite the environmental benefits of increased gas usage.
- Variability in the infrastructure is an increasing concern with respect to assuring system integrity and reliability. Differences in age, construction and material quality, and the ability to monitor and assess the status of systems are major concerns.
- While system safety has continued to improve, new demands on infrastructure and the risks posed by third-party damage are major concerns.

III. Vision and Goals

The vision for the nation's infrastructure reflects two primary drivers – the need to provide the desired services while meeting the expectations of customers and the general public alike, and the need for pricing that reflects the emerging trend to value-added services and products rather than mere delivery of a commodity.

VISION

“The gas infrastructure of the future will provide customer-specific service in a safe, reliable, environmentally benign, and efficient manner – at prices that are commensurate with the value provided.”

To achieve this vision, goals include:

- Increase pipeline capacity by 10% without changing infrastructure
- Improve the flexibility of the system to respond to load changes
- Decrease rate of safety incidents by 50% by 2010
- Establish a system to assess system integrity and trade-offs for use in planning and state and federal regulatory decisions by 2005
- Establish electronic systems to enable seasonal, daily, and hourly delivery of services by 2005
- Develop portfolio of technologies to reduce costs:
 - Reduce construction costs by >20% by 2005
 - Reduce operations and management costs by 30% by 2005, by 50% by 2010
- Decrease the rate of air emissions by 50% per million cubic feet by 2010
- Reduce outside force damage by 10% per year

IV. R&D Challenges

The role of technology in attaining the vision is key. Goals of enhancing the use of current infrastructure, cost reduction, development of value-added services, reduction of system vulnerability, and improved operations and maintenance all have significant technology components. Three general categories of technology needs were identified:

- Life extension and efficient use of existing infrastructure,
- Capacity development in new infrastructure
- System optimization and information management

Life Extension and Efficient Use of Existing Infrastructure

The development of improved methods and technologies can significantly enhance the integrity of the current infrastructure and maximize the throughput capacity. Areas of focus range from integrity assessment to monitoring and controls. Topics include:

- Low-cost pipeline rehabilitation technology
- Pipeline retrofit technology
- Non-intrusive integrity validation, particularly for local-distribution companies

-
- Underground pipe detection for local distribution companies
 - Robots to assess and repair pipes.

Capacity Development in New Infrastructure

The challenges in capacity enhancement include technology for improved transmission capabilities and for enhanced storage capacity. Topics include:

- Enhanced pipeline compression/looping technology to increase gas deliverability for power generation and peaking needs
- Technology to improve gas-storage injection and withdrawals, allowing increased volumes and higher flow rates without reservoir damage
- Stronger, less-expensive pipeline materials and advanced construction technologies for safer, cheaper pipelines
- Lower-cost construction and maintenance technologies
- Intelligent trenchless technology.

System Optimization and Information Management

The challenges cover two main areas: 1) improved capabilities to plan, monitor, assess, and control the transmission, storage, and distribution system and 2) new information management capabilities to enable new approaches to gas deliverability and services. Topics include:

- Pipeline in-service assessment tools
- Smart technology to provide capacity “bandwidth” expansion in current and new infrastructure without physical changes to the infrastructure
- Lower-cost system monitoring, control, and communications capability
- Real-time remote integrity monitoring, particularly for detection of third-party damage
- Remote emission monitoring systems for compression facilities
- Electronic and internet-based approaches for applications such as transmission/distribution/customer data acquisition, services and billing that responds to variable reliability and delivery cycle needs, and expedited permit filings and actions
- Validated technical databases and decision models to support regulatory requirements in infrastructure planning.

V. Appropriate Government Role

The government can serve an important role as part of an overall collaborative effort to ensure that the best, most cost-effective opportunities for a safe and reliable infrastructure are attained. There are three major areas where the government can serve an effective role.

- Establishing and communicating clear policies with respect to the role of natural gas in the nation’s energy policy. Natural gas is emerging as an environmentally preferred

energy source. Both regulatory and policy changes can help assure the benefits of natural gas use to the nation.

- Providing leadership in identifying and supporting R&D appropriate to the government role. This includes public benefits R&D and precompetitive R&D to keep the technology pipeline full.
- Serving as a “honest broker” in 1) identifying, validating, and promoting technology solutions to a wide range of stakeholders, including the public and the regulatory community and 2) identifying and supporting opportunities for government/industry collaboration.

The industry is in an era of rapid change and new challenges. It has responded with mergers, acquisitions, new products and services, and new partnerships. Many of the workshop participants are already active participants in a variety of collaboration R&D activities. Government must also respond to the change. Two specific areas can benefit.

- Analysis and restructuring, as appropriate, of the government research portfolio is needed to reflect the dramatic changes and opportunities for technology development. To facilitate best use of R&D resources and funding, DOE should critically review its R&D portfolio in terms of the relative emphasis on natural gas as a clean energy resource, and on the goals and structure of the department’s natural gas R&D portfolio.
- Opportunities for beneficial changes in regulatory processes can lead to improved use of the current infrastructure, and timely, cost-effective development of new infrastructure. The use of risk-management approaches, for example, has the potential for enhancing safety, reliability, and other public benefits while streamlining the costs and time required to meet the ultimate goals of regulatory requirements.

The change in the overall natural gas industry is fueling ongoing changes in private-sector plans and practices. Analogous changes in public-sector plans and practices can yield both improved public benefits and a better environment for business planning to meet infrastructure needs.

VISIONING WORKSHOP FOR NATURAL GAS INFRASTRUCTURE RELIABILITY

May 3, 2000
Pittsburgh, Pennsylvania

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APPENDIX B:

R&D ROADMAPPING WORKSHOP

TABLE OF CONTENTS

I.	Introduction.....	B-3
II.	Work Group 1: Life Extension and Efficient Use of Current Infrastructure	B-4
III.	Work Group 2: Capacity Enhancement in New Infrastructure.....	B-12
IV.	Work Group 3: System Optimization and Integrity	B-19

NATURAL GAS INFRASTRUCTURE RELIABILITY: R&D ROADMAPPING WORKSHOP

I. INTRODUCTION

Assuring the integrity and efficiency of the natural gas delivery infrastructure will be critical to achieving the high growth of gas usage projected by the Energy Information Administration and others. In a May 2000 Vision Workshop, senior executives from industry articulated their views of future business environments. They identified the key business, market, and technology drivers that will shape the requirements for a reliable gas infrastructure, articulated a vision for the infrastructure of the future, defined strategic goals to meet these requirements, and examined general R&D issues.

In a June 6-7, 2000 workshop in St. Louis, Missouri, participants defined major technical opportunities that can help achieve this vision and goals. The workshop was conducted in three breakout groups:

- Life extension and efficient use of existing infrastructure
- Capacity development in new infrastructure
- System optimization and integrity.

Working in parallel, each group examined the barriers, opportunities, and actions for technology development. This report presents the products of the three work groups.

In the workshop, participants in each group identified:

- Key barriers (business, market, technology, and others) to meeting the vision and goals for the system of gas infrastructure
- R&D opportunities to overcome these barriers
- Collaboration opportunities and actions.

In the following sections, the consensus workshop products of each group are presented. A group summary, barriers, opportunities, actions, and group participants are provided. The workshop products will be used to guide development of a *technology roadmap* that will serve as a framework for industry and government in implementing collaborative R&D activities.

II. WORK GROUP 1: LIFE EXTENSION AND EFFICIENT USE OF CURRENT INFRASTRUCTURE

Participants:

Larry Darrow	City Utilities of Springfield, MO
Steven Gauthier	IGT
George Gent	NW Natural Gas
Jack Hotzel	Duke Energy
Richard Huriaux	DOT, Office of Safety
Gerald Paulus	City of Mesa
Alexander Sarafin	NIPSCO – NiSource Co
Nancy Schultz	Williams Gas Pipeline
Wade Stinson	Memphis Light, Gas and Water
Jeff Vaughn	Laclede Gas Co

Observers:

Feridun Albayrak	TMS, Inc.
Christopher Freitas	DOE
Al Yost	National Energy Technology Laboratory

What are the Technology Barriers to Life Extension?

The top-voted ideas, shown in the Tables, all reflect concerns with outside/third-party infringements, damage, and repairs. The barrier for lack of “automated information data management” received both high- and med-priority votes; this statement was related to the smart-pipe concept mentioned in several of the other groups. A smart-pipe would be able to detect infringements and leaks and relay specific data relating that could be processed to determine repairs or actions necessary. The idea of even smarter, self-sealing pipes was also expressed. Other top-voted barriers in this session included “Ability to locate non-metallic pipes”, “Detect leaks quickly, efficiently”, “Internal and external inspection of pipes”, and “Guided boring technologies”. The top vote-getter for this category was “Dollars for technology improvement”.

Third-party damage was a topic of great concern to the entire group. There was debate over using this topic as a general category; however, it was felt that it is endemic to many of the categories listed in the tables and therefore would not constitute an entirely separate category. In fact, it was agreed upon that third party damage is not itself a barrier, but is a product of other barriers. Introducing sensory technologies to anticipate and discriminate infringements was discussed at some length, as was a means of detecting, containing and repairing both internal and external underground pipe damage. Improvements in keyhole, or slimhole technologies were identified as a critical area for development.

What R&D is Needed to Overcome Barriers to Existing Infrastructure?

Concerns with outside force detection came through in this, second, focus session as a clear priority. A separate category was created for this area, and the R&D need of “System of sensors and communications to detect when someone is near the line” received the top number of super- high- and med-priority votes. This idea clearly reflects the “smart-pipe” concept, which emerged in several of the breakout groups during this meeting. The other top-voted R&D need, “Way of seeing below ground – subsurface conditions, non-metallic detection of obstructions, and depth location”, was also clearly carried forward

from the barriers session and was discussed at some length. A related need, “Sensors on guided boring tool to detect other facilities (underground utilities)” received two of the super-priority votes.

It was felt by many in the group that many of the R&D needs identified were related to damage or infringements made by other underground industries. R&D conducted in this area could therefore benefit those industries as much as it would Natural Gas. This is perceived as a major hurdle for the investment of R&D dollars by companies, as the direct benefits to the company would be considerably smaller than the spillover benefits to other industries and society in general, especially as related to public safety. It was therefore felt that this is an area where basic R&D is needed and should be funded by the government and possibly through military programs. Additionally, other underground industries may be interested in coordinating in this effort as the results might also impact their operations.

One of the stated goals of this effort is to ensure that the increased capacity needs of future years are met. One of the significant barriers to this includes regulatory issues relating to pipe capacity. It was felt by many in the group that research should focus on the possibility of revising the allowable operating pressure limitations, which are currently set at 33% of design capacity. Increasing the allowable pressure even to 40% would allow significant increases in flow. This is an issue primarily for plastic pipes, but also for steel.

Several ideas related to policy changes, such as the two discussed above, were put forth in this session. It was felt by several individuals that R&D related to the policy needs for achieving the Natural Gas Industry goals would be beneficial.

Collaborative Roles and Action Planning

The first focus question in this session, “What is the Government Role in Life Extension?” resulted in several common trends spanning the five category headings, the strongest of which was **Collaboration**. Additionally, every general category included the ideas of public safety, benefits and reliability, all significant motivators for government involvement. Two other ideas were common to several of the categories: Accelerated development and military testing.

Collaboration and co-funding of efforts was identified as the strongest priority; there were 13 separate ideas under this focus question relating back to this point. Industry groups listed for collaboration included GRI, PRCI, NY Gas Group, NASTT, Battelle Southwest and others. The concern was voiced that these groups should be involved in R&D coordination to ensure that dollars are being leveraged in an effective manner and that duplication of efforts is avoided. It was also mentioned that the PRCI is attempting to ramp up private funding from major companies for R&D to replace the reductions in FERC funding to GRI.

The second focus of this session was to identify a time-frame for implementation of the various R&D priorities. The top-voted priorities across all time frames (near, mid and long) related back to the original barriers of infringement, damage and detection. In the near-term (0-3 years) the top votes were given to the ideas of “Locatable plastic pipe”, and “Laser optical methane and ethane detectors speed/accuracy/vibration”. In the mid-term (3-7 years) “Sensors on guided boring tool to detect other facilities (underground utilities)” received top votes. And for the long-term (>7 years) the top voted priority was “Intrusion detection device for pipes using sensors with communication when someone is near the line”.

Group 1: Life Extension and Effective Use of Existing Infrastructure

Table 1A. Technology Barriers Analysis

Ⓚ = Top Priority, ♦ = High Priority

INFORMATION TECHNOLOGIES	MATERIALS (INFRASTRUCTURE)	LOCATE PIPELINE	LEAK DETECTION	DETECTING AND PREVENTING OUTSIDE FORCE DAMAGE	STORAGE
<ul style="list-style-type: none"> Automated information data management ⓀⓀ♦♦ Data mining techniques lacking 	<ul style="list-style-type: none"> Early plastic pipe strength ♦ Strength limitations of current materials ♦ Odorant absorption into plastic pipe 	<ul style="list-style-type: none"> Ability to locate non-metallic pipe ♦♦♦♦ Correlating pipe locations and maps updated 	<ul style="list-style-type: none"> Need to detect leaks quickly ex. Flying over the line ♦♦♦♦ ! Non intrusive Ability of pipe to notify when damaged or leaking Ⓚ 	<ul style="list-style-type: none"> Real-time detection of third party damage Ⓚ♦ Improve communication with contractors on third party damage ♦ Detecting activity around the pipe ♦ 	<ul style="list-style-type: none"> Limited storage along the pipeline Ability to store gas in dense condition without high pressure ♦♦ Optimization of long term storage ♦ Need reduced cost peak shaving capability

Group 1: Life Extension and Effective Use of Existing Infrastructure
Table 1A. Technology Barriers Analysis (continued)

Ⓚ = Top Priority, ♦ = High Priority

ASSESSING PIPELINE CONDITION (WITH INTERPRETATION)	REPAIR/CONSTRUCTION TECHNIQUES AND MATERIALS/TOOLS	SYSTEM PLANNING	COMPRESSOR OPERATION AND MAINTENANCE ISSUES	GAS MEASUREMENT, MONITORING AND CONTROL	INSTITUTIONAL ISSUES
<ul style="list-style-type: none"> • Better internal and external inspection to know condition of pipe ♦♦♦♦ • Cannot detect geological subsidence (earthquake damage) • Do not know what the outside of the pipe looks like • Cannot look inside our infrastructureⓀ • We over replace because we do not know where the weak link is • Correlate pipeline condition with potential consequence • Statistical predictive models for condition of pipe vs. time ♦ • Long term effects of multi use pipeline utility corridors 	<ul style="list-style-type: none"> • Environment impacts of repairs • Municipality trench restoration requirements • Adjusting to challenges of working in highly populated areas • Existing pipe infrastructure renewal • Improve guided boring technologies ♦♦♦♦ • Repair and maintain pipeline without notice by landowner • Expensing to get down to line with current technology's keyhole tech • Do not have good one step pavement repairs maintenance ♦ • Ability to excavate quickly without damage to other underground utilities ♦♦♦♦ • Reduce labor associated with O&M • Less costly and faster repair • Cannot control gas once it is leaking (from third party – expensive) • Joining of pipe (plastic/steel) 	<ul style="list-style-type: none"> • Separation of system control models – sub optimization • Mismatch of growth development with capacity available • Generally behind in automation ♦ 	<ul style="list-style-type: none"> • Lower cost pulsation, vibration mitigation • Noise mitigation at low cost • Extending time between compressor overhaul ♦ • Fuel consumption (compressors, etc.) • Exhaust emission tech For older equipment ♦ • Older compressors do not have sufficient flexibility 	<ul style="list-style-type: none"> • Corrosive gas from upstream – prevention and detection • What is Btu mix at different points in the line • Metering issues: mismatches to track inventory – no hints where to look for leaks • Cannot clean up gas on the front-end • Improved communications with end users before load effects happen • Real time low cost meter reading capability • Need low-cost remote control valves with feedback to system (valves get covered over or lost) • Better integration between upstream and downstream data • Lack of real-time consumption information ♦ • Automated facilities Ⓚ • Tracking unaccounted – for gas (accounting) 	<ul style="list-style-type: none"> • Facility siting difficulty • Operating pressure limitations ♦♦♦♦ • Expense of O&M effort does not match associated risk • Dollars for technology improvements ⓀⓀⓀⓀ

Group 1: Life Extension and Efficient Use of Existing Infrastructure

Table 1B. R&D Needs Analysis

⌘ = Top Priority, ♦ = High Priority, • = Medium Priority

OUTSIDE FORCE DETECTION	PIPELINE ASSESSMENT TECHNOLOGIES	LEAK DETECTION AND CONTROL	MATERIALS
<ul style="list-style-type: none"> • System of sensors and commune to detect when someone is near the line ⌘⌘⌘♦♦••••• ! Intrusion detection device ! Acoustic sensors 	<ul style="list-style-type: none"> • Non-contact cast iron joint locator • In-line inspection tool to detect ♦•• ! Metal loss deformation cracks ! Miniature camera • Internal sensors carried with gas in flow to sense flow conditions ! Optical capability to detect: water, debris, old equipment • Evaluate pipeline coating condition without excavation • Rules or classes of M.A.Op. (Max allow Op. Pressures) (Research into) ♦• ! New studies to show safety 	<ul style="list-style-type: none"> • Develop leak detection equipment to improve accuracy and speed ♦• • Device to contain leaks ! Donut-like device vs. capture gas • Liquid/foam to plug leaks • Smart meter with real-time leak detection ♦♦•• ! Sensor tech to notify customer of leak ! Autoconnect and disconnect • Thermo-graphic imaging ⌘ ! Leak detection ! Seg migration underground ! Pinpoint dig location • Smart shut off system to compensate for desirable high flows ♦ • Laser optical methane detection •• • Optical ethane detectors • 	<ul style="list-style-type: none"> • Locatable plastic pipe (a tag in the material) ♦♦♦•• • Coating on top of polyethylene pipe that protects and allows detection ♦ ! Without bedding or shading can be extruded ! “Intelligent” pipeline coating • High pressure plastic pipe materials ♦•••• • Low cost superior performing field applied pipeline coatings • Corrosion protection through cathodic protection system • ! Solar cathodic to reduce maintenance costs • • Ability to predict the rate of corrosion for specific conditions • Development of composite pipe material with desirable charact • • ! Low cost, stronger, more durable, hot and cold tolerant • Smart-pipe that can send signal back ♦• ! Sensor ! Fiber optics • More reliable and predictable pipe material qualities to allow reduced safety factors • • ! Tighter design factors to enable high pressures

Group 1: Life Extension and Efficient Use of Existing Infrastructure

Table 1B. R&D Needs Analysis (continued)

Ⓚ = Top Priority, ♦ = High Priority, • = Medium Priority

STORAGE	GAS CONTROL	INFORMATION COLLECTION AND PROCESSING	COMPRESSORS	CONSTRUCTION AND REPAIR TECHNOLOGIES
<ul style="list-style-type: none"> Improved methods of gas storage <ul style="list-style-type: none"> ♦ Big storage – gas co. owned Storage at home that is safe, efficient, low cost <ul style="list-style-type: none"> • Hydrates Storage optimization study to see where best suited geol sites along existing pipelines 	<ul style="list-style-type: none"> Inexpensive way to control all line valves on the system Gas tracing mechanism – tagging molecules (cost-effective, isotope mix, etc.) 	<ul style="list-style-type: none"> Develop better real time metering to measure <ul style="list-style-type: none"> ♦ • • ! Heat content ! Volumes One database of all underground facilities that all can access Web-based locating/comm./ Notification, closed-loop system <ul style="list-style-type: none"> • • ! Excavator one-call center to web utility perform locate reload to web Automated data collection and management of field operations <ul style="list-style-type: none"> ♦ ! Leak survey ! Compressor performance ! Job site evacuation Standard pipeline communication architecture and protocols <ul style="list-style-type: none"> ! Upstream/down stream pipelines ! Customers and companies Integrating line locating with map updated maybe GPS or other real-time <ul style="list-style-type: none"> • 	<ul style="list-style-type: none"> Lower cost variable speed drives for electricity driven centrifugal compressors Lower cost emission control for natural aspirated engines <ul style="list-style-type: none"> ♦ • Low cost noise mitigation – acoustic noise cancellation <ul style="list-style-type: none"> • Life extension of critical reciprocating compressor components <ul style="list-style-type: none"> • Improved surge control systems for centrifugal compressors <ul style="list-style-type: none"> • Life extension of gas turbines especially hot path components <ul style="list-style-type: none"> • 	<ul style="list-style-type: none"> Research on repair and joining of plastic pipes Way of seeing below ground <ul style="list-style-type: none"> ♦ ♦ ♦ ♦ ♦ ! Subsurface conditions “x-ray like” ! Pipe locator that can detect non-metallic underground obstructions (pipes and other obstacles) ! Low cost method of depth location Keyhole construction tools <ul style="list-style-type: none"> • • Out of the ditch emergency gas shut off <ul style="list-style-type: none"> • • Harmonic excavations Internal no-dig repair <ul style="list-style-type: none"> ♦ ! Liners for leak repair Sensors on guided boring tool to detect other facilities (underground utilities) <ul style="list-style-type: none"> Ⓚ Ⓚ ♦ • ! Non-metallic lines Excavation lay equipment that more vertical to minimize width of right-of-way needed for repair <ul style="list-style-type: none"> • Flowable fill material for paving nee <ul style="list-style-type: none"> ♦ ! Sets up like concrete Robotics to perform various construction and maintenance activities <ul style="list-style-type: none"> ! Fusion of pipe

Group 1: Life Extension an Efficient Use of Existing Infrastructure

Table 1C. R& D Timeframe Analysis

Each ♦ represents one vote

NEAR TERM	MID TERM	LONG TERM
<ul style="list-style-type: none"> • Keyhole construction ♦ • High pressure plastic pipe materials (~300 psi) ♦♦ • Laser optical methane and ethane detectors speed/accuracy/ vibration ♦♦♦ • Out of ditch emergency gas shutoff ♦ • Locatable plastic pipe ♦♦♦♦ • Develop better real-time metering to measure ! Heat content ! Volumes ♦ • In-line inspection tool to detect: ♦♦ ! Metal loss ! Deformation ! Cracks (mini-camera) • Lower cost emission control for natural aspirated engines ♦♦ 	<ul style="list-style-type: none"> • Research into repair and joining of plastic pipes ♦ • Internal no-dig repair techniques ♦ • Smart meter with real time leak detection • Sensor on guided boring tool to detect other facilities (underground utilities) ♦♦♦♦ • Distributed storage at commercial/utility end user that is safe, efficient, low cost ♦ 	<ul style="list-style-type: none"> • Robotics to perform various construction and maintenance activities ♦ • Smart-pipe that can send signals back ♦♦ • Very high pressure plastic pipe >300 psi • Intrusion detection device for pipes using sensors with communication when someone is near the line ♦♦♦ • Technologies to see subsurface conditions: ♦ ! Non metallic pipe ! Obstructions ! Depth

Group 1: Life Extension and Efficient Use of Existing Infrastructure

Table 1D. Government Roles

	WHY GOVERNMENT SHOULD BE INVOLVED?	GOVERNMENT PLANS	NEXT STEPS
SENSORS IN GUIDED BORING TOOL TO DETECT OTHER FACILITIES	<ul style="list-style-type: none"> • Benefits many industries • Public safety issues • Fundamental technical component 	<ul style="list-style-type: none"> • Provides research funds • Catalyze industries coming together 	<ul style="list-style-type: none"> • Look at military applicators • Coordinate with GRI, NY Gas Group, NASTIT
LOCATABLE PLASTIC PIPE/DETECTION OF NON-METALLIC PIPE	<ul style="list-style-type: none"> • Safety re • Reliability issues • Public benefits 	<ul style="list-style-type: none"> • Accelerate development for common benefit • Enable critical mass of \$ • Long-term testing at government facilities • Collaborating R&D 	<ul style="list-style-type: none"> • Literature review on state-of-art • Cofunded activities • Collaborate with association/manufacturing/government/users
LOWER COST EMISSION CONTROL PIPELINE COMPRESSOR ENGINES	<ul style="list-style-type: none"> • Reliability • Major environmental benefit • Government has been involved – regulations • Efficiency benefit 	<ul style="list-style-type: none"> • Accelerate development • Encourage OEM involvement • Reformer research 	<ul style="list-style-type: none"> • Collaborative forum to determine what engine types are critical
IN LINE INSPECTION TOOL	<ul style="list-style-type: none"> • Public safety • Reliability • Environmental • Capacity increase 	<ul style="list-style-type: none"> • Current role in damage detection • Maintain Battelle testing facility • Neutral facilitator 	<ul style="list-style-type: none"> • Collaboration with GRI/PRCI/Battelle Southwest Research Institute, etc.
LASER OPTICAL METHANE AND ETHANE DETECTORS WITH SPEED PINPOINTING ACCURACY/VIBRATION	<ul style="list-style-type: none"> • Public safety • Climate change benefits 	<ul style="list-style-type: none"> • Accelerate development • Simulate/accelerate R&D investment 	<ul style="list-style-type: none"> • Military technology • Identify/create collaborative efforts • Bring together industry • Identify funding sources
INTRUSION DETECTION DEVICES FOR PIPES USING SENSORS WITH COMMUNICATION WHEN SOMEONE IS NEAR THE LINE	<ul style="list-style-type: none"> • Public safety • Reliability • Expensive • High risk 	<ul style="list-style-type: none"> • Fund basic research • Fund applied research • Cofunding to lead to implementation 	<ul style="list-style-type: none"> • Look at military technologies • Collaborative activities • Characterize technical limitations

III. WORK GROUP 2: CAPACITY ENHANCEMENT IN NEW INFRASTRUCTURE

Introduction

Assuring the integrity and efficiency of the natural gas delivery infrastructure will be critical if the natural gas industry hopes to achieve the high growth of gas usage projected by the Energy Information Administration and others in the future. In order to meet the need to provide the desired services while meeting the expectations of customers and the general public, the industry will need to identify methods for enhancing the capacity of its existing infrastructure. If the industry expects to attain this goal, they must first identify the key barriers (market, technology, and others) which threaten their vision and goals. Identification of these goals was a top priority of the fifteen participants in this facilitated session.

Participants included:

Participants:

Ken Beckman	International Gas Consulting, Inc.
Terry Boss	INGAA
Kirby Chapman	Kansas State University (Natural Gas Machinery Lab)
Shelley Corman	Enron Gas Pipeline Group
James Fangué	Texas Utilities
Earl Lewis	Baltimore Gas & Electric Company
Graham Midgley	Heath Consultants, Inc.
John S. Parker	Key Span Energy
Sudheer Pimputkar	Battelle
Stephanie Rubio	Southern California Gas Company
Robert Torbin	Foster-Miller, Inc.
Mike Whelan	GRI

Observers:

Dan Driscoll	National Energy Technology Laboratory
Jeff Hawk	Albany Research Center/DOE
Margie Tatro	Sandia National Laboratory

Technology Barriers for Capacity Enhancement

Barriers to enhancing the capacity of the infrastructure have a technical component, but are largely non-technical in nature. Aside from specific technical barriers, categories include Regulatory Barriers, Economic Barriers, Safety & Reliability, Perception Barriers, and Education Barriers.

In the technical area, there is a need for technologies to locate and identify subsurface facilities. A need for tools to evaluate pipeline integrity also exists. There is also an overall barrier to new technologies within the system and the industry is not utilizing many of the innovative technologies that currently exist. This can be attributed to a combination of perception and education problems, in addition to economic risks associated with new technologies.

Concerns about regulatory related barriers are dominant. "Institutional barriers have kept the industry locked in the box" according to the group. Permitting and regulatory issues are a problem, whether dealing with new pipelines or with stored gas.

Perception plays an integral role also because it is a major driver in the regulatory arena. For example, increasing public expectations related to environmental health and safety, add to the increasing complexities of the regulatory and permitting process. Expectations related to convenience of service also contribute to the overall problem of gas distribution. Dialogue with the regulatory community and with the public is needed in order to overcome the perception barrier. A more strategic approach is needed so that institutional barriers can be met and the regulatory and permitting process be streamlined. There is a need for consistency with standards, whether they are safety, regulatory, design, or other associated standards.

Economic issues are also perceived as a significant barrier. With the uncertainty concerning the future needs of customers, as well as the uncertainty of the market in the future, companies are tightening their financial belt, thus limiting their willingness to invest in research and development of new or improved technologies. Return on investment is regulated and inadequate.

It is difficult to maintain an adequately trained workforce. Technology improvements outpace training. In addition, old-fashioned, conservative thinking results in a fear to try new and/or innovative approaches to an issue.

Meeting Needs for Capacity Enhancement with Research & Development

The regulatory and permitting problems impede technical progress and are thus worthy of R&D efforts. Technology and regulatory policy are directly linked so it is hard to speak of one without considering the other. There is a need for strategic planning on regulatory issues to insure that regulations are reasonable and consistent and will facilitate the industry meeting the needs of its customers. Current regulations often inhibit private investment in new technologies and delay construction. Many of the issues considered have tremendous potential benefits to the public but the technology in and of it cannot be effective unless it is supported with reasonable and consistent policy.

Key themes associated with R&D opportunities include:

- Technologies related to monitoring and maintaining pipeline integrity. This includes multifunctional sensor technologies development. Cost effective systems that can detect and pinpoint leaks as well as determine residual pipeline life and third party damage are of importance. The ability to map an underground system is also needed.
- Technologies, which would contribute to system optimization. These include modeling algorithms for compressor station components as well as real-time electronic metering and customer feedback capabilities.
- Construction technologies related to new pipelines as well as those associated with upgrading the existing infrastructure. Included in this area are directional drilling capabilities, subsurface location techniques and excavation limitation by using keyhole tools.
- Materials technologies. These involve the upgrading of low-pressure pipes to high pressure and the development of “smart” (self-healing or self-monitoring) pipes and pipe coatings.

While storage issues are important, it is believed that they would be met by the industry as a result of market forces.

Timeframe When the Result of the R&D Would Begin to Show Financial Return

A majority of the R&D effort must be accomplished quickly so that financial return will be shown within a 0-7 year period. This is possible because a number of these efforts would be building on existing technologies. New development is feasible, but often expensive. A given technology could produce results in a quicker manner following an infusion from the government. This infusion can be financial, or collaborative by means of bringing information together under one research effort. Beyond the seven-year timeframe, the government could aid in supporting longer-term R&D efforts in areas such as multi functional sensors.

Role of the Government

In most instances, the primary reason the government should be involved in the proposed R&D efforts revolves around the fact that most of these technologies provide benefits that are shared across the public. Many of the technologies would actually be applicable to all underground utilities such as electric, water, sewer, and telecommunications, in addition to the natural gas industry. Public safety, as well as reduced costs to the end users, is also potential benefits. Much of the R&D has too high a cost-benefit ratio for a single company.

While the government should provide funding to meet some of the needs, several can be cost-shared. The government should also facilitate groups and/or agencies working together to find a resolution to the problem. DOE can be a positive force in bringing parties together to resolve existing barriers. Finally, the very fact that the DOE specializes in energy justifies the need for their participation in overcoming the barriers which the natural gas industry faces as it strives to meet the needs of its customers in the future. With the DOE's expertise, many of these issues can be resolved in a more timely, less expensive manner, with the public reaping the benefits of such collaborative efforts.

Group 2: Capacity Enhancement in New Infrastructure

Table 2A. Technology Barriers Analysis

K = Top Priority, **◆** = High Priority

REGULATORY BARRIERS	ECONOMIC BARRIERS	SAFETY & RELIABILITY	PERCEPTION BARRIERS	EDUCATION BARRIERS	SPECIFIC TECHNICAL BARRIERS
<ul style="list-style-type: none"> • Permitting Process KKKKK◆ • Environmental regulations are not always reasonable ◆◆◆ • Institutional barriers are created by codes and standards ◆◆ • Regulatory change K • Right of way acquisition ◆ • Right of way rules limit construction and increase cost ◆ • Long approval times cause early commitment to equipment and route ◆ • Increased regulation due to accidents 	<ul style="list-style-type: none"> • Cost risks related to using new technologies K◆ • Regulated ROI not adequate ◆◆◆ • Conflict between unregulated commodity and regulated infrastructure (e.g. storage) ◆◆ • Failure to use other infrastructure investments ◆ • New markets are price sensitive ◆ • Only using gas drivers • Limited technology sharing increases costs • Competition from other energy sources • Lack of research money • Assets are non-moveable • Telecommunications construction is increasing labor costs 	<ul style="list-style-type: none"> • Variable, inconsistent safety construction standards ◆◆ • Delivery system is vulnerable ◆ • Need adequate model of infrastructure 	<ul style="list-style-type: none"> • Increasing public expectations on safety, environment, and convenience ◆◆◆ • Perception that new technology is expensive ◆◆ • Landowner resistance to new pipe ◆ • Perception that pipelines are dangerous • Only using gas drivers • Perception that all pipe lines are the same 	<ul style="list-style-type: none"> • Difficulty maintaining labor force ◆◆◆◆ • Emerging technology outpaces operator training K • Old-fashioned, conservative thinking on materials ◆◆ • Imperfect communication between developers and end-users ◆ • Public lacks understanding of infrastructure • Lack of cooperation between construction and operations people 	<ul style="list-style-type: none"> • Lack of technologies to locate and identify subsurface facilities KK◆◆◆ • Inadequate tools for evaluating pipeline integrity for non-pigable lines ◆◆◆◆◆ • System not amenable to new technology K◆◆ • Current materials have limited operating pressure ◆◆◆ • Low pressure systems limit distribution K • Lack of lower cost methods to reinforce large distribution gas mains ◆ • Lack of precise knowledge of grid layout ◆ • Costs for automating storage, injection and withdraw

Group 2: Capacity Enhancement in New Infrastructure

Table 2B. R&D Analysis

Ⓚ = Top Priority, ♦ = High Priority, • = Medium Priority

PIPELINE INTEGRITY	SYSTEM OPTIMIZATION	CONSTRUCTION	MATERIALS	PERMITTING	STRATEGIC PLANNING
<ul style="list-style-type: none"> • Cost effective leak detection and pinpointing ♦♦♦♦♦•• • “Smart” system to interpret data from multi-functional sensors: Residual life, third party damage, and mapping ♦♦♦♦♦•• • Improve “smart” pigging technology ♦♦♦♦♦• • Advanced pipeline repair techniques •• 	<ul style="list-style-type: none"> • Modeling algorithms for compressor station components Ⓚ♦♦♦•• • Enhanced accuracy, low cost, real-time electronic metering and customer feedback ♦♦♦♦• • Novel delivery techniques ♦♦ • Improved methods for flow detection and control ♦♦ • Useful, cost-effective extraction of energy at pressure regulator stations •••• • Development of virtual pipeline system test bed ♦ • Station level, real-time optimization algorithms •• • Analyze potential synergies with other infrastructures • • Combined unit for electricity generation and compression • • Improved modeling (hydraulic - for optimization) • • Smart curtailment devices • • Systems analysis of large electric-drive compressors 	<ul style="list-style-type: none"> • More sophisticated underground directional drilling technology ⓀⓀ♦♦♦♦•• ! Technology combining trench-less pipe installation and local underground radar • 3-D subsurface facility locating techniques ⓀⓀ♦♦• • Re-examine design factors ♦♦♦♦•• • Key-hole type tools to minimize excavation ♦♦♦♦•• • Automated pipeline construction and restoration ♦ • Common conduit into homes •• • Illumination system for new pipes •• • Low maintenance pipeline for high density or remote areas 	<ul style="list-style-type: none"> • Lining technology to upgrade low pressure lines to higher pressure Ⓚ♦♦♦• • Development of high pressure composite transmission pipe Ⓚ♦♦• • Pipeline coating research for development of “smart” multi-functional coatings Ⓚ•••• • “Smart” pipe ♦♦♦♦♦♦♦•• ! Self-healing pipe ! Self-monitoring pipe • Advanced plastic technologies for use with IHP pipelines • • New materials for cathodic protection 	<ul style="list-style-type: none"> • More realistic economic model for cost/benefit/risk analysis used in regulations ⓀⓀⓀ♦♦•• ! Decision support system to minimize interagency conflict ! Study of risk and how to place it into context ! Use existing imaging techniques when possible • Study how to make the permitting process better ♦♦♦♦♦♦♦•• • Develop a web-based risk assessment program that companies could use anonymously so that data could be integrated Ⓚ• • Gas turbine catalytic combustion • • Better integrate satellite imaging into the regulatory process 	<ul style="list-style-type: none"> • Improved methodology to focus common R&D efforts ♦♦ • Strategic research plan with defined deliverables •

Group 2: Capacity Enhancement in New Infrastructure

Table 2C. R&D Time Frame Analysis

Each • represents one vote

0-3 YEARS	SHORT TO MID	3-7 YEARS	MID TO LONG	MORE THAN 7 YEARS
<ul style="list-style-type: none"> Modeling algorithms for compressor station components • Re-examine design factors • More realistic economic model for cost/benefit/risk analysis used in regulations • Study how to make the permitting process better • • • Develop a web-based risk assessment program that companies could use anonymously so that data could be integrated 	<ul style="list-style-type: none"> Improved “smart” pigging technology • Key-hole type tools to minimize excavation • 	<ul style="list-style-type: none"> Cost effective leak detection and pinpointing • • Enhanced accuracy, low cost, real-time electronic metering and customer feedback • • More sophisticated underground directional drilling technology • • • • Lining technology to upgrade low pressure lines to higher pressure • • Pipeline coating research for development of “smart” multi-functional coatings • • 	<ul style="list-style-type: none"> 3-D subsurface facility locating techniques • • • • Development of high pressure composite transmission pipe • • • “Smart” pipe 	<ul style="list-style-type: none"> Multi-functional sensors: Residual life, third party damage, and mapping • • • • •

Group 2: Capacity Enhancement in New Infrastructure

Table 2D. Government Role

TOP R&D PRIORITIES	WHY GOVERNMENT SHOULD BE INVOLVED?	ROLE OF THE GOVERNMENT	FIRST STEPS
Development of High Pressure Composite Pipe	<ul style="list-style-type: none"> • Lower cost to end user • Provides a public benefit • This is a huge, multi-dollar, multi-year, high risk program • The time-frame is too long for industry alone to meet the need 	<ul style="list-style-type: none"> • Provide funding for research 	<ul style="list-style-type: none"> • Literature search • Establish “state of the art” • Identify gaps • Cost/benefit analysis • Workshop • Issue a Solicitation
Study How to Make the Permitting Process Better (At All Levels of Government and All Agencies)	<ul style="list-style-type: none"> • Government controls the problem and the solution • This is a political problem • Need a quick solution • DOE could be a positive influence on other agencies 	<ul style="list-style-type: none"> • Lead and facilitate rationalization of process 	<ul style="list-style-type: none"> • Identify participants • Form consensus of problem • Cost/benefit analysis • Streamline permitting process at all levels and all agencies • Write policy
More Sophisticated Underground Directional Drilling Technology	<ul style="list-style-type: none"> • Applicable to all utilities • Allows expansion of gas distribution • DOE manages energy • Lower cost to end user • So it will get done quickly • Damage prevention 	<ul style="list-style-type: none"> • Cost sharing • Facilitate getting funding from other agencies (Industry should lead with the rest) • Assist with technology acceptance (regulatory) 	<ul style="list-style-type: none"> • Frame a solicitation to find gaps in current technology as well as cost/benefit analysis of enhancements • Analyze what other industries would benefit
3-D Subsurface Facility Locating Techniques	<ul style="list-style-type: none"> • Applicable to all utilities • Allows expansion of gas distribution • DOE manages energy • Lower cost to end user • So it will get done quickly • Damage prevention 	<ul style="list-style-type: none"> • Funding (possible cost sharing with DOE) • Funding from other agencies • Needs Basic Research 	<ul style="list-style-type: none"> • Assess state of the art and emerging technologies • Issue RFP for concepts to National Labs, Universities, etc.
Multi-functional Sensors: Residual Life, Third Party Damage, and Mapping	<ul style="list-style-type: none"> • Public safety • Funding needed • Need for standardization • Enables proactive maintenance • Sensor technology is high tech and government has information (National Labs, DOD, etc. could help) • So it will get done quickly 	<ul style="list-style-type: none"> • Funding • Partnership (industry should lead so that it will become commercial and they should involve pipe-liners, instrumentation, vendors, etc.) • Facilitate regulatory process • Government assists with protocol 	<ul style="list-style-type: none"> • Frame a solicitation • Identify integrity impediments, identify how to measure them, and identify the sensor • See what is out there

IV. WORK GROUP 3: SYSTEM OPTIMIZATION AND INTEGRITY

Participants:

1. Bob Bass	Southwest Research Institute
2. Ron Fisher	Argonne National Laboratory
3. Chris Flood	American Public Gas Association
4. Paul Gustilo	American Gas Association
5. Gerald Harmon	Austell Gas System
6. Ray Harris	National Fuel Gas
7. Roddie Judkins	Oak Ridge National Laboratory
8. Bill Price	Public Service Electric and Gas
9. Dan Schuler	Cinergy
10. Glen Schuler	Columbia Gas Trans

Observers:

1. Rodney Anderson	National Energy Technology Laboratory
2. Bob Carrington	INEEL
3. Make Knaggs	National Energy Technology Laboratory

What are the technology barriers to systems optimization and integrity?

The barriers were considered in the context of the six program goals contained in the workshop materials handout. Three industry buzzwords that the group felt were important to improve upon but that were not stated explicitly in the program goals are “reliability, deliverability, and efficiency.”

The group did not focus on information technology exclusively, but gave strong priority to required upgrades in the physical plant, that is the pipes, compressors, sensors, and other hardware that make up the gas infrastructure. Specifically, capacity and deliverability are limited by the both absolute pressure limits on the pipelines and the rate at which pipeline pressure can be changed in response to changes in flowrates using existing compressor technology. Another barrier to system optimization is a lack of good information on the physical condition of the pipelines, as well as data on operational parameters at specific times and location along the pipeline. The idea being that in order to optimize the system, one needs to understand it better, especially the older sections.

Safety incidents are another important limitation on system performance, specifically pipeline ruptures caused by third parties during excavation activities. The fact that it is difficult and expensive to find and fix leaks is another barrier.

A reoccurring theme was that there existed technologies to remedy many of the barriers. The problem was that they cost too much. There are a lot of pipelines and many maintenance crews. In order for a solution to be viable in the natural gas infrastructure industry, it needs to be relatively inexpensive.

What R&D is needed to address the barriers?

The group recognized that significant effort is ongoing to address many of the barriers identified, and they did not feel they held enough expertise in the various areas of study to make defensible recommendations

and prioritizations. The group went forward with the process with the caveat that the following is by no means definitive information.

All of the R&D needs identified by the work group are presented in the tables presented after the summary. The following are several highlights:

- Development of new materials for pipes that would be tougher, more resistant to corrosion, able to withstand higher pressure, and lower cost than existing materials
- Recognizing the huge existing infrastructure of pipelines, develop an internal coating that can improve the strength of existing pipelines and also make them smoother to reduce frictional losses. A key component would be a method for apply the coating. It would need to be low-cost and such that the coating material did not get into compressors, flowmeters, storage facilities, and other ancillary equipment and disrupt operations.
- Inexpensive systems to locate and provide images of underground pipes would be of great value, especially if they could identify the materials of construction without requiring ??? techniques. Beyond simply finding underground pipes, systems that could assess the integrity of pipes, especially small diameter pipes, would be helpful in monitoring system integrity.
- A longer term idea was “something” that would provide a quantum improvement in the amount and quality of information that operators had about their pipeline systems. One idea would be to use the pipes themselves as the medium for information transmissions, thus removing reliance on radio signals and satellites.
- The group felt that there was room for improvement in the management of transient situations. A better fundamental understanding of dynamic flow as well as instrumentation that could provide the needed information and response frequency could be helpful.

There are a number of safety related items that could be pursued and implemented in the near-term. Many of the ideas regarding improvements in the physical plant and data acquisition and control require more fundamental breakthroughs and would provide results in the longer term.

Why is government support of the R&D projects merited?

With respect to a justification for government involvement, the group came up with an acronym, Additional Safety, Reliability, and Deliverability (ASRD) which applies to most of the R&D projects. The word ‘additional’ emphasizes that the existing natural gas infrastructure is safe, reliable, and meets loads swings adequately, and that R&D efforts are aimed at incremental improvements and at maintaining systems performance as the demand for natural gas grows. Compressor-related projects have the additional benefit of reducing pollutant emissions and fuel consumption. Also, many of the fundamental research areas will provide benefits to industries outside natural gas T&D.

What are appropriate roles for the government?

Regarding appropriate government roles, the group recognized that there would be areas in which the government would be able to take a lead role in developing technology or building on existing work through related efforts in the National Labs, DoD, the space program, and others. However, there are some areas where more of a supplemental role would be necessary to assist efforts that industry has underway. Through the collaborative efforts discussed, the research strengths of the government, combined with the operating skills of the industry would be fully utilized to provide meaningful research

which would provide benefits to satisfy an appropriate mixture of short-term and long-term goals. The group concluded that the government's expertise could also play a role in disseminating information and taking other actions to ensure that safety-related technology was adopted and deployed by both natural gas T&D companies and/or excavation companies.

What are the logical next steps?

For all the recommended actions, the group placed an emphasis on program collaboration strong with entities currently involved in related and relevant technology development. Several association including AGA, APGA, GMRC, GRI, and PRCI were recommended as being able to help identify projects and set priorities. The group also recommended that the NETL program be structured so that performers with established expertise in the various areas (e.g., gas operating companies, equipment manufacturers, research organizations) would have an incentive to participate. The details of how the program might collaborate with the various organizations was recognized by the group as substantive issue in its own right, and one that was worth discussing in the future.

Group 3: System Optimization & Integrity

Table 3A. TECHNOLOGY BARRIERS ANALYSIS

k = Top Priority, **◆** = High Priority

PHYSICAL PLANT (PIPES, COMP, STORAGE...)	SAFETY	DATA ACQUISITION AND CONTROL	SYSTEM OPTIMIZATION AND MODELING	TECHNOLOGY TRANSFER	REGULATION	INTERDEPENDENCI ES
<ul style="list-style-type: none"> Material limits on T&D ◆◆◆◆◆◆◆◆◆◆ Insufficient and flexible compression technology kk◆ Cost of upgrading old system ◆◆ Increase system operating pressure Inflexibility of infrastructure High system losses due to compression Pressure response too slow 	<ul style="list-style-type: none"> Do not know when someone hits your line kk Warning/stopping third parties before hit k◆◆◆ Difficult and expensive to locate all kinds of pipes ◆◆ 	<ul style="list-style-type: none"> Monitor physical condition kkk◆◆◆◆◆◆◆◆◆◆ ! Lack of data on leaks and corrosion ◆ Monitoring operational parameters ◆◆◆ ! Information on pressure and volumetric flow at time and specific pipe segment ! Do not know flow losses well enough Communication link between sensors and operation control centers 	<ul style="list-style-type: none"> Convert data to real time business management tools ◆◆◆◆◆ Lack of predictive pipe failure models ◆◆◆◆ Methodologies to optimize across systems ◆◆ Many load swings at customer sites Variation in gas quality, for example the effect on hydrate formation Institutional reluctance within the industry to change the system 	<ul style="list-style-type: none"> Technology expensive kk◆◆◆◆◆ Technology unreliable Standards development 	<ul style="list-style-type: none"> Prescriptive regulations ◆ Regulations and public barriers to new pipeline ◆ Environmental regulations 	<ul style="list-style-type: none"> Vulnerability of information systems, especially in the communication link between the field and control centers k◆ Growing interdependencies (i.e., on electric generation and communication systems)

Group 3: System Optimization & Integrity
Table 3B. R&D Needs Analysis

k = Top Priority, **◆** = High Priority, **•** = Medium Priority

PHYSICAL PLANT				SAFETY	DATA ACQUISITION AND CONTROL	SYSTEM OPTIMIZATION AND MODELING	TECHNOLOGY TRANSFER
PIPES	COMPRESSION	STORAGE	M&R				
<ul style="list-style-type: none"> Materials optimization kk◆◆◆◆ ◆◆◆◆◆ ! New composite material◆◆ ! Tougher ! Corrosion resistant ! Higher pressure ! Low cost Internal coating for old pipe ◆◆◆◆ ! Increase flow eff. Strength ! Low application method – no impact on storage or metering Improved low-cost methods to identify and repair pipelines ◆◆◆◆ Further development of infrared thermal detection system(s) ◆◆◆ ! Lower cost Non-methanol hydrate mitigation technology • 	<ul style="list-style-type: none"> Next generation compressor design ◆◆◆ Develop flexible compression technology ◆◆ Lower cost compressor engine technology to address environmental regulations ◆ Optimize exist capital stock of compressors to improve rangability and efficiency ! Operate closer to surge line 	<ul style="list-style-type: none"> Develop improved storage facilities kk◆◆◆ ! Improved operational procedure ! Well head/hole pressure and flow measurement ! Design ! Large-scale reservoirs ! Operations management 	<ul style="list-style-type: none"> Develop improved low cost pipeline metering device(s) k•• 	<ul style="list-style-type: none"> Imaging and locating underground pipes kkk◆◆◆◆ ! Identify materials of construction Integrity assessment kk◆◆◆ ! Above ground non-invasive technology for small diameter pipe (e.g., sonic imaging) ◆◆ ! Smart pigging ! In-situ tools to assess strength of existing pipes ! Consider stress establish MAOP Develop predictive pipe failure models k◆◆◆◆◆◆ ! User friendly <ul style="list-style-type: none"> - Capable of being used to manage an entire system R&D on warning systems to install on excavation equipment to warn operator(s) ◆◆◆ Need quantitative risk assessment methodologies ◆◆◆ - Prioritize pipeline inspection and repairs Develop new materials to withstand the effects of drilling and boring ••• 	<ul style="list-style-type: none"> Improved system data acquisition ◆◆◆◆◆ ! Third party damage ! Corrosion and leakage monitoring ! Send signal through pipe Sensors for dynamic applications (press, flow , etc.), must give quick response ◆◆◆◆◆◆◆ •• Sensors to detect onset of hydrate formation • Improve robotics to support deploy of sensors SCADA <ul style="list-style-type: none"> - Lower cost - Expand - Standardize - Make robust 	<ul style="list-style-type: none"> R&D understand of transient flow and impact on D&E ◆◆◆ Regional model ◆ Operational models – human factors analysis Better predictive models for hydrate form 	<ul style="list-style-type: none"> Technology evaluation and certification ◆◆◆◆◆◆◆

Group 3: System Optimization & Integrity
Table 3C. R&D Time Frame Analysis

Each ♦ represents one vote

R&D CATEGORY	NEAR TERM 0-3 YEARS	MID TERM 3-7 YEARS	LONG TERM 7+ YEARS
Safety	Imaging and locating of underground pipes (MoC) ♦♦♦♦ Quantitative risk assessment methodologies ♦ Predictive pipe failure models ♦	Warning systems on excavation equipment ♦♦♦♦ Integrity assessment ♦♦♦	
System Optimization and Modeling	Transient flow R&D impact on D&E		
Technology Transfer	Establish technology evaluation and certification methodology		
Physical Plant		New composite materials ♦♦♦ Improve existing compressor rangeability emissions and efficiency ♦♦ Materials optimization ♦ Improved low-cost pipeline metering devices ♦ Internal coating for old pipe ♦ Improved low-cost methods to identify and repair pipeline (live) Increase efficiency and reduce cost of existing storage	Next generation compressor ♦♦ Develop infra-red thermal detection systems ♦♦ Identify and develop novel on-site storage concepts ♦♦
Data Acquisition and Control		Sensors for dynamic applications (low cost)	Improved system data acquisition ♦♦

Group 3: System Optimization & Integrity
Table 3D. Government Role / Next Steps

R&D AREA	PROJECT TITLE	WHY IS GOVERNMENT \$ NEEDED?	WHAT ROLE SHOULD THE GOVERNMENT PLAY?	NEXT STEPS
Safety	Warning systems on excavation equipment	Public safety Multi-industry benefits	Lead development Disseminate information to ensure adoption	Establish collaboration with DOT, state government, and industry
	Imaging and locating of underground pipes	Additional Safety Reliability Deliverability (ASRD)	Lead development Disseminate information to ensure adoption	Establish collaboration with DOT, state government, and industry
	Integrity assessment	ASRD multi-industry benefits	Supplement industry effort	Collaborate with industry to identify projects and set priorities
Physical Plant	New composite materials	ASRD multi-industry benefits	Supplement industry efforts for activities with near term focus, lead development effort longer term R&D	Collaborate with industry to identify projects and set priorities
	Infra-red thermal detection systems	Additional Safety Multiple industry benefit (specifically in water and sewer applications)	Supplement industry effort	Work with companies doing it now, Department of Defense
	Improve existing compressors (Rangeability, Efficiency, Environmental performance)	Increased efficiency will reduce environmental emissions and fuel consumption multi-industry benefit	Supplement industry effort	Collaborate with compressor manufacturers, operating companies, and instrument and control manufacturers
	Next generation compressor	Increased efficiency will reduce environmental emissions and fuel consumption multi-industry benefit	Lead development	Collaborate with compressor manufacturers, operating companies, and instrument and control manufacturers
	Identify and develop novel on-site storage	Deliverability Environmental benefit	Supplement industry effort	Collaborate
Data Acquisition and Control	Improved system data acquisition	ASRD	Supplement industry efforts for activities with near term focus, lead development effort longer term R&D	Collaborate with other government agencies

About NETL and the Strategic Center for Natural Gas

The National Energy Technology Laboratory (NETL) is federally owned and operated. Our mission statement is "*We Solve National Energy and Environmental Problems.*" We perform, procure, and partner in technical research, development, and demonstration to advance technology into the commercial marketplace, thereby benefiting the environment, contributing to U.S. employment, and advancing the position of U.S. industries in the global marketplace.

The Strategic Center for Natural Gas, located at NETL, was created by the Secretary of Energy in December 1999 to provide a focal point within the Federal government to look out for the future of natural gas "from borehole to burnertip." Its primary mission is to coordinate Federal activities in natural gas research and development, analysis, and policy development to support the national strategy for natural gas.

Building on the foundation NETL has in its natural gas technology program, the center works with industry, other government agencies, and the research community to ensure that the U.S. can meet future supply, transport, and demand needs. This "systems approach" provides the vision and roadmap to develop the nation's resource base, to build and maintain reliable transport and distribution, and to ensure clean and efficient use of natural gas.

For more information please visit our website:

<http://www.netl.doe.gov/scng/index.html>

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